Modeling of Dust Effect on Solar Panels in Abu Dhabi

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Abstract

We have performed light scattering calculations from dust particles using the T-matrix model to estimate the effect of dust accumulation on the solar panel surface. The accumulated dust is modeled as a superposition of different dust layers with a scattering cross-section. Our calculation shows that after only a few days, the solar panel output performance was reduced by at least 10%, which is rather significant. We conclude that regular surface cleaning of the solar panels is required every 10 to 15 days on the average under normal weather conditions to maintain close to 100% of the normal performance.

1. Introduction

The effect of dust accumulation on solar panels has received much interest recently [1-4]. In particular, this has been of great interest for applications on the solar energy powered vehicles used in the explorations of the surface of the planet Mars due to its dusty environment. This has attracted a lot of attention from NASA to improve the energy efficiency of their Mars exploration rovers to be able to continue their mission. The accumulated layer of dust reduces the amount of sunlight reaching the solar cells which in turn reduces the amount of electric power produced.

The environment in Abu Dhabi is similar in the sense that we have a few sand storms per year and almost no rain fall. This leads to the question whether or not dust is also a problem for solar energy production in Abu Dhabi. A similar question has recently been considered by a few other researchers based in the U.S.A. and Europe under different climate conditions. In particular, a study undertaken in Germany shows that the productivity of a solar panel drops by 9% to 20% from the possible output with different soiling depositions on the surface of the solar panels [5]. This has led to the conclusion that there should be some cleaning process every 12 days or so in order to minimize the effect of dust on the output power of the solar panels. In most situations, either there is a sufficient number of rain falls on a regular basis, which leads to a self-cleaning process of the panels, or there is not enough dust to require cleaning of the panels. This is not the case in the Abu Dhabi region.

2. Theoretical background

In this paper, we propose to use well-established light scattering theory to model the effect of dust accumulation on the solar panel electric power output [6]. Our scattering calculations are based on an improved version of Mie theory which is restricted to spherical, homogeneous, isotropic and non-magnetic particles in a non-absorbing medium [7]. As it is well known, dust particles are hardly ever spherical or homogeneous; therefore a more advanced scattering theory is needed for good convergence and better accuracy. During recent years some scattering methods for non-spherical and non-homogeneous particles have emerged. For the case of ellipsoids and finite cylinders, surface discretization methods have been developed and used. One of the most commonly used surface discretization methods is the T-Matrix [7]. On the other hand, scattering by completely inhomogeneous particles has been computed using volume discretization methods [7-9]. More complex and time-consuming methods exist but which are not necessary in our situation.

To model the scattering process, we have used the standard Mie theory for light scattering from spheroid particles [10, 11]. In our model, we have assumed that the dust particles have a spherical form with no interaction between the particles. This technique is generally referred to in the literature as the T-matrix approach. It is based on expanding the transmitted and scattered fields into series of spherical vector wavefunctions (M and N). The scattered field, E^s, may be expanded as [6]:

$$E^s(r) = \sum_{n=1}^{N} D_n [a_n^s M_n^3(kr) + b_n^s N_n^3(kr)] \tag{1}$$

A similar expansion is written for the incident field, E^i. The expansion coefficients of the scattered field, a^s *and b,* are related to the coefficients of the incident field a^i *and* b^i by the "transition matrix" or T-matrix as shown in Equation (2):

$$\begin{bmatrix} a^s \\ b^s \end{bmatrix} = -T \cdot \begin{bmatrix} a^i \\ b^i \end{bmatrix} \tag{2}$$

The scattering cross-section, Q_{sct}, is, by definition, an area that reduces the power of the incident radiation due to the scattering mechanism. This is given in terms of the T-matrix as follows [12]:

$$Q_{sct} = \frac{2\pi}{k^2} \sum_{i,j=1}^{2} \sum_{n=1}^{\infty} \sum_{p=1}^{\infty} \sum_{m=0}^{\min(n,p)} (2 - \delta_{m0}) \left| T_{mnp}^{ij} \right|^2 \tag{3}$$

In Figure 1, we show the calculated scattering cross-section based on Equation (3) for different particle radii.

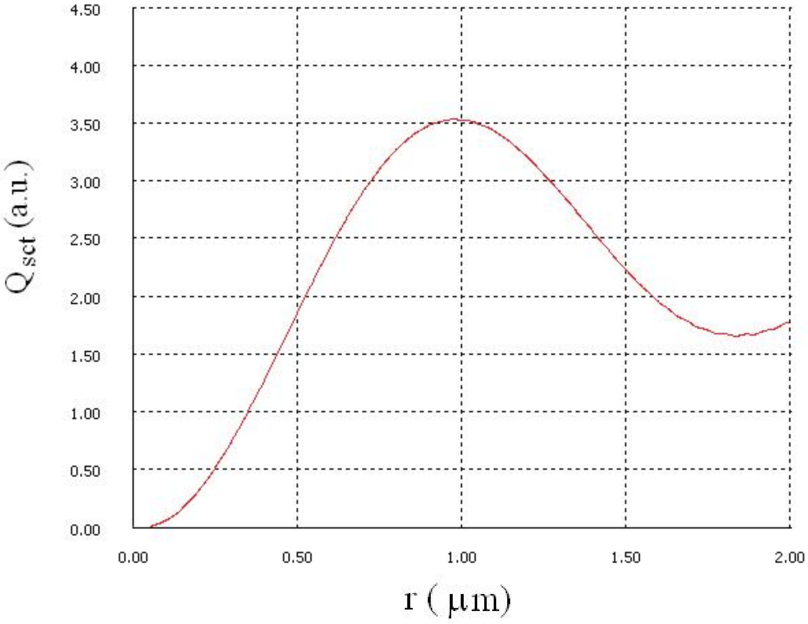

Figure 1: Scattering cross-section calculated from a spherical particle with different radius.

From the scattering cross-section we can determine the net flux of photons Q_{net} from the sun that will arrive at the surface of the photocell to be absorbed and give rise to a short-circuit photocurrent J_{sc} . This is given by the following expression [13]:

$$J_{sc} = e\int_0^{\infty} Q(E)b(E)dE \tag{4}$$

where *Q(E)* is the incident spectrum which is proportional to the net flux of photons Q_{net}. On the other hand, *b(E)* is the quantum efficiency which represents the probability that an incident photon of energy E will deliver one electron to the external circuit. In our case, we use an efficient photocell with $b(E) = 1$ and a material with a gap energy E_q . We can rewrite Equation (4) as follows:

$$J_{sc} = e\int_{E_g}^{\infty} Q(E)dE \tag{5}$$

The emitted energy flux density or irradiance, *L(E)*,is given by:

$$L(E) = E \cdot Q(E) \tag{6}$$

Substituting this into Equation (5) yields:

$$J_{sc} = e\int_{E_g}^{\infty} \frac{L(E)}{E} dE \tag{7}$$

In general, the power changes as dust, settling from the atmosphere, and accumulates on the top of the solar panels. The thicker the dust layers, the more loss of power is expected. We have proceeded by modeling the dust particles into successive layers of individual scattering particles. Only first order scattering is considered, with no absorption by the particle layers. From a simple calculation, assuming a steady dust accumulation with an average particle deposition v, we can determine the average number of layers m deposited per day.

The transmitted light through each layer is generally given as a function of the transmission coefficient, β, defined as follows:

$$\beta = \frac{Q_{net}}{Q_i} \tag{8}$$

so that for each layer we have:

$$Q_{net} = \beta \times Q_i \tag{9}$$

and for m layers we have:

$$Q_{total,net} = \beta^m \times Q_i \tag{10}$$

This is the estimated total transmission cross-section, $Q_{total,net}$, through m layers of dust particles. We assume an ideal photocell where each photon reaching its surface will give rise to one conduction electron to contribute to the photocell generated current density. The total short-circuit current density, J_{sc},is similarly given by:

$$J_{total,sc} = \beta^m \times J_i \tag{11}$$

where J_i is the normal short circuit current of the photocell for a specific day and region with no dust particles present. In our case, J_i represents the daily average short-circuit current for an ideal photocell with no dust particles present for the Abu Dhabi region.

3. Results and discussion

The objective of our modeling process is to obtain a representation of the average daily short-circuit current density, J_{sc}, for a standard photocell as a function of time (days). To model this scattering process, we have used an average dust particle diameter in the Abu Dhabi region of 3.5 μm, and an average dust deposition rate of approximately 35 μm/day [14]. The photocell size is considered to be 1 cm^2. Using these parameters, we estimate the average number of dust particles that would be deposited on the surface of this photocell for one layer to be 2.86×10^3. We then calculate the scattering cross-section Q_{sct} from a single dust particle using the Mie theory as described earlier. From Figure 1, this was calculated to be $Q_{sct} = 1.75$. In order to avoid over estimating the scattering process due to the dust particles settling on the top of each other, we have modeled the total daily number of dust particles on the solar cell into a number of close packed single layers of these particles.

In general, the power changes as dust, settling from the atmosphere, accumulates on the surface of the solar panels. The thicker the dust layers, the greater the loss of power and efficiency. We can clearly deduce that a solar panel exposed to more dusty area like the sandy desert of Abu Dhabi is more likely to lose significant power and require regular cleaning. The preliminary results of our calculations lead to interesting conclusions. Our calculations are performed assuming a slow and typical rate of dust deposition on the panels.

We have found that we can expect to lose up to 10% of the photocell power performance with only a small dust deposition rate, which is equivalent to a few days under normal conditions with no sand storms. In fact, this is quite a large loss if we consider the case of a residential solar panel where it takes more than six years to see any profit from a newly installed solar energy system.

The flux of photons coming from the sun reaches the surface of the earth with a magnitude that depends upon the location on earth and the period of the day. This is regularly measured in different locations worldwide by satellite or on the ground [15-17]. The quantity measured is the irradiance, L(E), or energy flux density. Figure 2 shows a recent measurement of the observed daily irradiance in the Abu Dhabi region [15].

Using Equation (7) and the daily irradiance we can calculate the short-circuit current, J_{sc}, for a standard photocell. The result is shown in Figure 3.

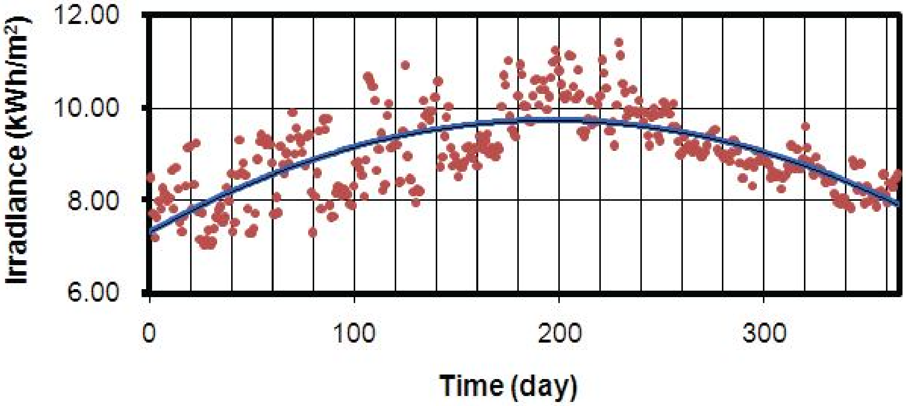

Figure 2: Observed daily irradiance in the Abu Dhabi region with a polynomial fitting curve [15].

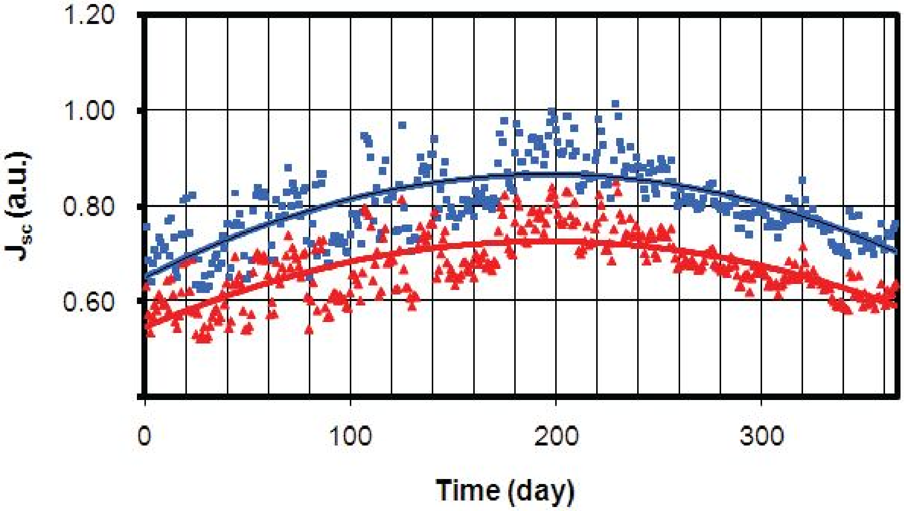

Figure 3: Normalized daily variations of the short-circuit current, J_{sc} ,for a standard photocell in the Abu Dhabi region, without dust (squares) and with a high dust deposition (triangles) as discussed in the text. The line represents a second order polynomial fitting curve to the data.

Ideally, the surface of the photocell should receive all the expected photons from the sun. In the real case, however, there will be some dust particles settling on the surface of the glass plate covering the photocell. Some of the light coming from the sun will then be scattered by these dust particles and will not make it to the photocell. The longer the period of time the solar cell is exposed, the more dust will be collected on the surface and consequently the more significant this light scattering processes becomes.

The normalized short-circuit current, $J_{total,sc}$, with the modeled dust particle deposition for the 365 days of the year in the Abu Dhabi region is also shown in Figure 3. We can clearly see that the effect of dust deposition on the photocell short-circuit current density, J_{sc}, is reduced by more than 10% after about 10 days. This is a significant loss and needs to be reduced to improve solar energy production, especially considering that this loss increases with time. To restore photocell power performance to within no more than 10 % reduction, one would need to perform periodic photocell glass surface cleaning about every 10 to 15 days. This is of course under normal weather conditions with no sand storms. In the case of sand storms, cleaning would need to be performed immediately after the storm to restore the normal performance of the photocell. The method by which one would need to clean the surface of the solar cell or prevent the dust from deposition on its surface is another issue that has been addressed by several authors recently. This is especially important for photocells that are located in a remote and dusty environment like on the surface of Mars for example [1,2].

4. Conclusions

We have performed light scattering calculations using the T-matrix approach to estimate the effect of dust deposition on the photocell performance in the Abu Dhabi region. Due to the very limited rain fall and the high level of dust present in this region, one would expect this effect to be larger and to require more attention in this region than in other parts of the world with regular rain falls. Our results show that we can reach up to 10% reduction in the photocell short-circuit current density in just 10 to 15 days. Based on our calculations, solar cell surface cleaning is necessary to maintain close to 100% performance. From our model we have estimated that the cleaning process should take place on a regular basis every 10 to 15 days on average to keep the photocell performance as high as 90% of its maximum performance under normal conditions. Regular solar panel cleaning is recommended, especially in the Abu Dhabi region where rain is rare and dust is often present. Further simulated laboratory testing and measurements are in progress.

5. References and Bibliography

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Author biography

Dr. Abdellatif Bouchalkha received a Bachelor degree in physics (U.S.A., 1986), a Master in Solid State physics (USA, 1989), and a Ph.D. in Optoelectronics (U.S.A., 1993). He worked with femtosecond lasers to study the ultra-fast optical switching and electrical properties of nano-scale semiconductor devices and structures. He has also worked with Rayleigh and Brillouin scattering in various materials. His main area of research is the study and design of special sensors and instruments. Currently he is working on a research project to design an autonomous instrument for oil pipe inner surface inspection.